H. J. Morel-Seytoux, A. R. Simpson, and R. A. Young
Assessing waterlogging controls I: hydrologic model
Proceedings of the Specialty Conference on Advances in Irrigation and Drainage: Surviving External Pressures, American Society of Civil Engineers Irrigation and Drainage Division, Jackson, Wyoming, USA, July 20-22, 1983: 10 p

Source:
http://dx.doi.org/10.1061/9780784479018.ch03

Assessing waterlogging controls I: hydrologic model

by

Morel-Seytoux, H.J., Young, R.A. and Simpson, A.R.

Proceedings of the *Specialty Conference on Advances in Irrigation and Drainage*

Citation:
Morel-Seytoux, H.J., Young, R.A. and Simpson, A.R. (1983). “Assessing waterlogging controls I: hydrologic model”, proceedings of the *Specialty Conference on Advances in Irrigation and Drainage*, Irrigation and Drainage Division of the American Society of Civil Engineers, Jackson, Wyoming, 20-22 July.

Assessing Waterlogging Controls I: Hydrologic Model

H. J. Morel-Seytoux, A. R. Simpson, and R. A. Young*

The application area and the hydrologic model used to perform the overall management study of how to control waterlogging are very briefly described in this paper. Two important features of the model are (1) the realistic description of the exchange of water between the water courses and the connected unconfined aquifer and (2) the surface drainage of irrigation water to downslope areas where the water percolates. The validity and the value of the model are reported in a second paper by the same authors.

INTRODUCTION

Waterlogging is one of the most prevalent and serious problems associated with irrigation in arid regions of the world. In its physical aspects, the problem arises as follows: The excess of irrigation water applications above evapotranspiration losses percolate below the crop root zone, eventually reaching the groundwater table. The water table will in time rise, reaching the crop root zone and even, in lower lying areas, the land surface. Saturated or waterlogged soils are usually detrimental to crop yields, and the rising water table often leads to salinization, a further detriment to crop production. When water is applied to a crop, most of the moisture leaves the soil through evapotranspiration; but the salts remain in the soil. If the water leaching past the root zone does not contain as much of the dissolved salts as was applied with the irrigation water, the net result is an unfavorable salt balance resulting in a salt accumulation within the soil and a loss in productivity. Since these problems are often companions, any actions, such as pumping down the water table or drainage systems which relieve waterlogging, will do much to relieve salt accumulation in soils (Luthin, 1957).

Systematic drainage and reclamation has been recorded as early as the pre-Christian era in Greece, where a system of drainage ditches to reclaim apparently waterlogged land has been reported (FAO/UNESCO, 1973). A good technical review of the problem is provided by, among others, Van Schilfgaarde (1974). Dunford (1982) gives a detailed discussion of salinity control and how it is used in drainage system design.

In contrast to the abundant technical literature in hydrology, soils, and agronomy, comprehensive economic analyses of the waterlogging problem are relatively rare. The White House-Interior Department

---

*H. J. Morel-Seytoux is Professor of Civil Engineering, A. R. Simpson is a former Research Assistant in Civil Engineering, and R. A. Young is Professor of Economics, Colorado State University, Fort Collins, Colorado 80523.

Panel on Waterlogging and Salinity in the Indus Basin (1975) studied the serious problems in what was then West Pakistan. Johnson (1975) analyzed the problem in the Closed Basin, San Luis Valley, Colorado, with a detailed economic model of water allocation, but employed a relatively simplified hydrologic model. Fitz et al. (1980) examined the economic feasibility of installing a tile drainage system in a central California irrigation district.

Study Area

The study area (Figure 1) selected comprises a portion of the San Luis Valley in south central Colorado containing a region of waterlogged land adjacent to the Rio Grande in the central to southern part of the Valley. The physiography is that of a high mountain desert (7500 feet above sea level) with mean annual precipitation of 7.5 inches.

The study area consists of approximately 500 square miles lying to the south of the closed basin and contains a wedge of land between the Rio Grande and Conejos River.

Years of large-scale diversion of Rio Grande water into the study area south of the river, combined with the practice of maintaining the water table sufficiently high for sub-irrigation have resulted in waterlogging and some salinization of tens of square miles of lower lying lands. The appropriation doctrine, as presently interpreted in Colorado, has encouraged a system where each individual considers only the results of his actions (on his farm) even though downslope impacts have become obvious. Therefore, some type of collective action, which represents a modification of the existing operating procedures, appears desirable. Institutional changes (drainage and improvment districts) and investments in conveyance and drainage facilities would contribute to solving the problem.

Objectives

The overall objective of the study was to develop a systematic approach to predicting impacts of alternative procedures for management of irrigation water so as to minimize waterlogging and salinization and to improve water-use efficiency. The specific model is developed for and applied to the San Luis Valley, Colorado; but the general methodology will be applicable to other areas. To achieve the overall objective, a computer simulation model was developed capable of prediction of the impact of management and control measures on groundwater status and river flows throughout the affected area; and was operated for a selected set of control measures, so as to predict their impact on water table and river flows.

The remainder of this paper describes briefly the components and interactions incorporated into the simulation model. A companion paper by the same authors discusses the management strategies tested with the model, and reports on their predicted impacts as compared with the historical operation of the system (Young et al., 1983).

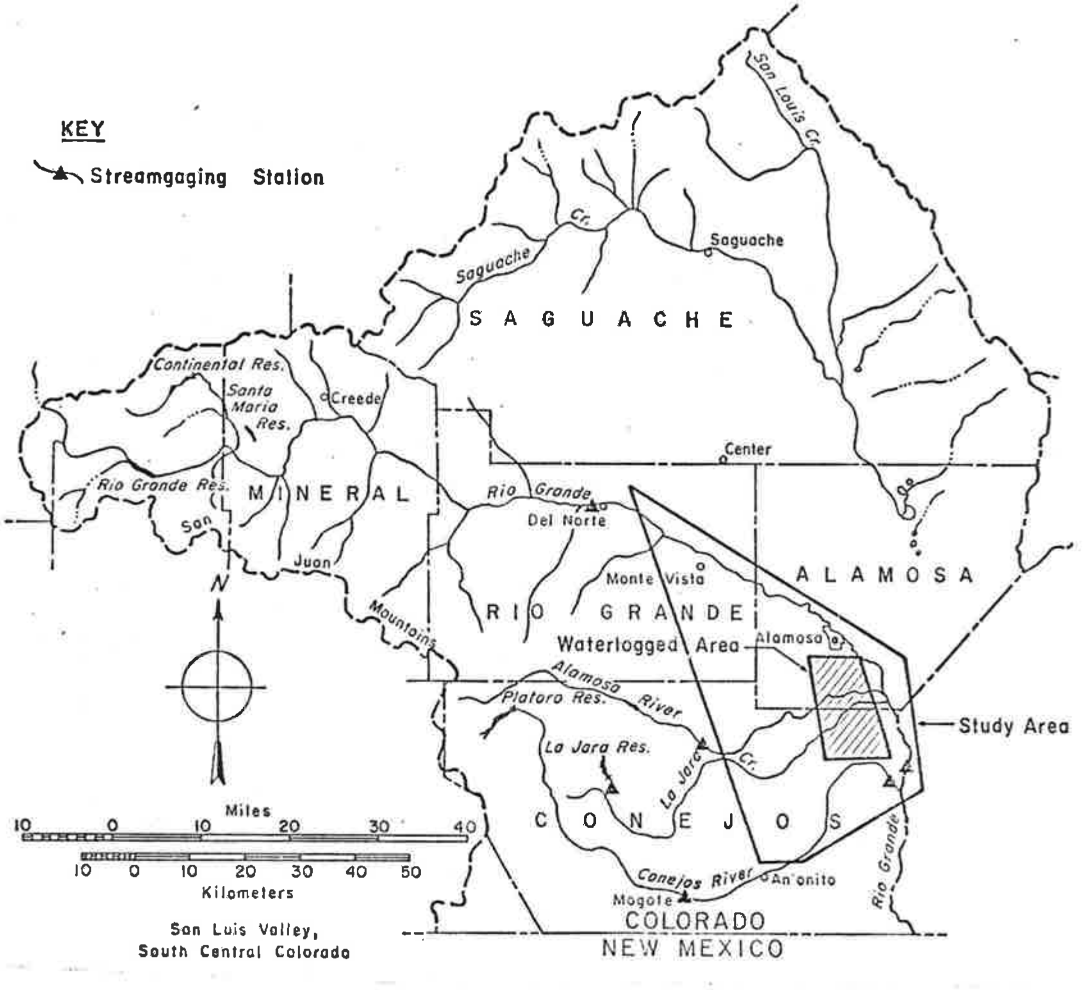

Figure 1. Location Map of Study Area, San Luis Valley, Southern Colorado

TYPE OF HYDROLOGIC MODEL REQUIRED

The hydrologic model should enable the study of various management strategies and their effect on the waterlogged area. The model needs only be a planning (management) model rather than an exact operating model. It should give an overall idea of changes which occur when various management strategies are simulated.

Components of the System

The system to be studied includes the natural features of a stream-aquifer system along with the modifications introduced by man's engineering (canals, dams, reservoirs, wells, ditches) and agricultural practices (center pivot sprinkler irrigation, furrow irrigation). To manage the system, each of the components must be described in a precise quantitative way in the hydrologic model.

Modeling of the unconfined aquifer and streams in the study area and of the stream-aquifer interaction forms the basis of the hydrologic model. The already existing discrete kernel approach (Morel-Seytoux, 1979) conveniently provides the unconfined aquifer response both to pumping from wells and seepage flow from the river, as well as the river response to pumping from wells. Three types of excitation which need to be considered in the hydrologic model include upstream inflows, stream diversions, and the net aquifer withdrawals (Morel-Seytoux, 1979, p. 12).

One feature of the model needs to be the calculation of the unconfined aquifer level at various locations within the waterlogged area and in the surrounding irrigation areas. Irrigation areas to the north, west, and southwest of the waterlogged area contribute to the build-up of the levels of the unconfined aquifer due to irrigation methods employed in the San Luis Valley. These irrigation areas and the methods used by farmers to manage surface water diversions from the rivers and the groundwater withdrawals need to be considered.

To model a stream-aquifer system, such as the one being considered in the San Luis Valley, the interaction between the stream and aquifer must be recognized. The term "return flow" refers to the exchange of water between the river and unconfined aquifer or vice versa. These return flows depend on the level of water in the river and the level in the unconfined groundwater aquifer in the vicinity of the river. Consequently another feature needed in the model includes the calculation of the river stage and its subsequent variation along the river and the calculation of the unconfined aquifer level in the neighborhood of the river.

Rainfall, streamflow, and evaporation as well as crop requirements for water during the growing season are factors that must be considered in the development of a hydrologic model of the study area. The Water Rights Doctrine for distribution of irrigation water and the Rio Grande Compact Agreement which attempts to ensure water supply for the downstream states and Mexico constrains the way in which certain quantities of water may be used. These two legal aspects are important features of the model.

Time Horizon, Time Increment and Grid Size Selection

Three important parameters need to be decided upon before considering any of the components or interactions in detail and before gathering data for the model. These are the time horizon, the time increment, and the grid size.

In order to assess the long term effects of the various management strategies a reasonable time horizon over which the hydrologic model simulates the study area is required. On the other hand the cost of a simulation run increases with time. Consideration of these factors led to the selection of a time horizon of 12 years.

A one-month time increment is used in the hydrologic model. This is regarded as a time period which adequately reflects the seasonal variation of the system. The water year is from October to the following September and has been used in the hydrologic model as the basic year. Simulation runs begin in October. The frost-free season in the valley ranges from 90 to 115 days. Surface water diversions occur during April to October.

For modeling of the study area it is necessary to overlay it with a finite difference grid of calculation cells. Within each cell the effect of pumping, the aquifer properties, or the evaporation, etc., are assumed to be uniformly distributed over the cell. However all these variables (may) vary from a cell to the next. The first decision regarding the grid system was to adopt a square grid. The closer the grid points are to one another the more accurately the model represents the physical problem. On the other hand, the greater the number of grid cells the greater the computer costs and storage requirements. Based on these computer costs and storage, along with the NASA infrared photographs which are used to determine location and size of the irrigation areas, a grid system spacing of one mile was selected. This spacing is as small as practical for using the infrared photographs, however, one mile is small enough so as to adequately model the study area.

PHYSICAL COMPONENTS OF THE SYSTEM

The physical components of the study area which are considered in the computer simulation hydrologic model include the rivers, the aquifers, the irrigation areas, the irrigation water distribution systems, and the waterlogged area. Sources of irrigation water for the study area include surface water, confined, and unconfined groundwater. The primary source of surface water inflow is derived from snowmelt. The three main supplies of surface water to the study area are the Rio Grande, the Conejos River, and the La Jara/Alamosa Rivers. Water from these sources is conveyed to the irrigation areas via man-made irrigation canals. The three major canals carrying Rio Grande water south are the Monte Vista Canal, San Luis and Rio Grande Canal, and the Empire Canal. Five major irrigation areas have been identified depending on source of surface water supply. Appropriately these areas are the Empire irrigation area, Monte Vista irrigation area, San Luis and Rio Grande irrigation area, Conejos irrigation area, and La Jara/Alamosa irrigation area. Figure 2 shows these five major irrigation

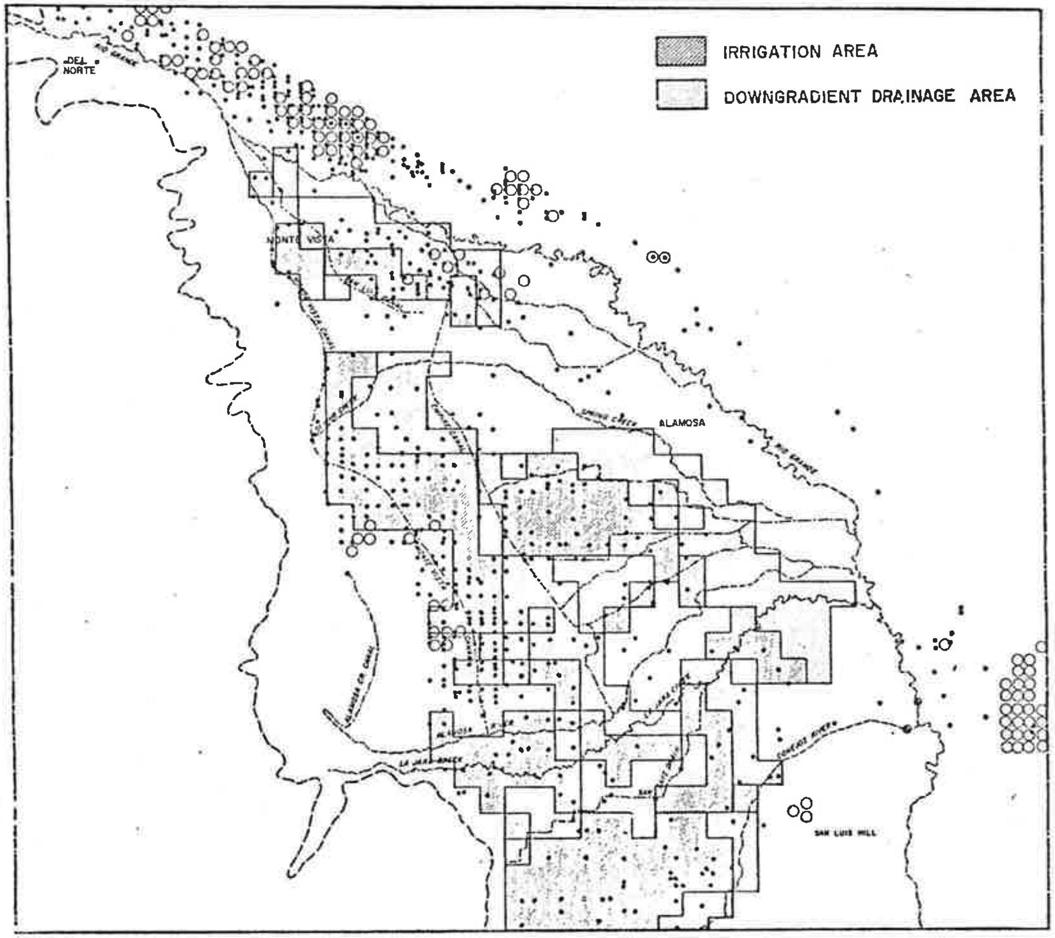

Figure 2. The Major Irrigation Areas and the Downslope Drainage Areas within the Study Area

areas and the downslope drainage areas (where overland drainage from the irrigation areas finally percolates to the unconfined aquifer).

The Waterlogged Area

The unconfined aquifer elevation is calculated in each time step at 34 square mile grid cells within and close to the waterlogged area. The location of these 34 cells is shown on Figure 3.

Rivers

The rivers considered in the computer model which are important to the study area are the Rio Grande, Conejos River, and the La Jara Creek/Alamosa River system. The San Luis Drain which runs close to the Alamosa River is also considered in detail, as it is a major channel available to carry excess water away from lower portions of the study area (see Figure 3). The drain serves a double purpose. The upper reaches collect return flow and then redistribute this water to farms further downstream while the lower parts serve as a true drain for irrigation return flow. In the lower parts the drain joins the La Jara Creek which flows into the Rio Grande.

The Rio Grande and Conejos River are modeled in detail in the simulation model. They are both assumed to be hydraulically connected to the unconfined aquifer. On the other hand, the La Jara Creek and Alamosa River are not modeled in nearly as much detail. These two water courses only carry a small amount of water except during high spring snowmelt flows when flooding can occur and many diversions to adjacent irrigation areas are made. All the spring streamflow from the two streams, most of which is regulated by reservoirs on the La Jara Creek and Alamosa River is assumed to be diverted to the La Jara/Alamosa irrigation area which is comprised of scattered lands in the center of the study area adjacent to and west of the waterlogged area. The nearby San Luis Drain is modeled in detail and is assumed to be hydraulically connected to the unconfined aquifer.

The grid system overlayed on the study area divides a river into reaches. A river reach is that portion of a river contained within a square mile grid cell. River reach numbers are associated with each of the river cells beginning at the upstream end. The Rio Grande has 57 river reach cells, the Conejos River has 17 river reach cells while the San Luis Drain has 21 river reach cells.

In order to calculate the return flow between the unconfined aquifer and the river or vice versa for a particular river reach, the stage in the river reach and the average unconfined aquifer level in the river reach grid cell is required. The river stage can be obtained using a stage-discharge relationship. However, the average unconfined aquifer level requires knowledge of the excitations at adjacent and nearby grid cells to be able to calculate the effect on the aquifer level at the river reach under consideration. The result is that three separate river grid systems are required. These include a grid system for the Rio Grande, for the Conejos River, and the San Luis Drain. This enables the unconfined aquifer levels in each of the 95 river reaches to be calculated in each time step.

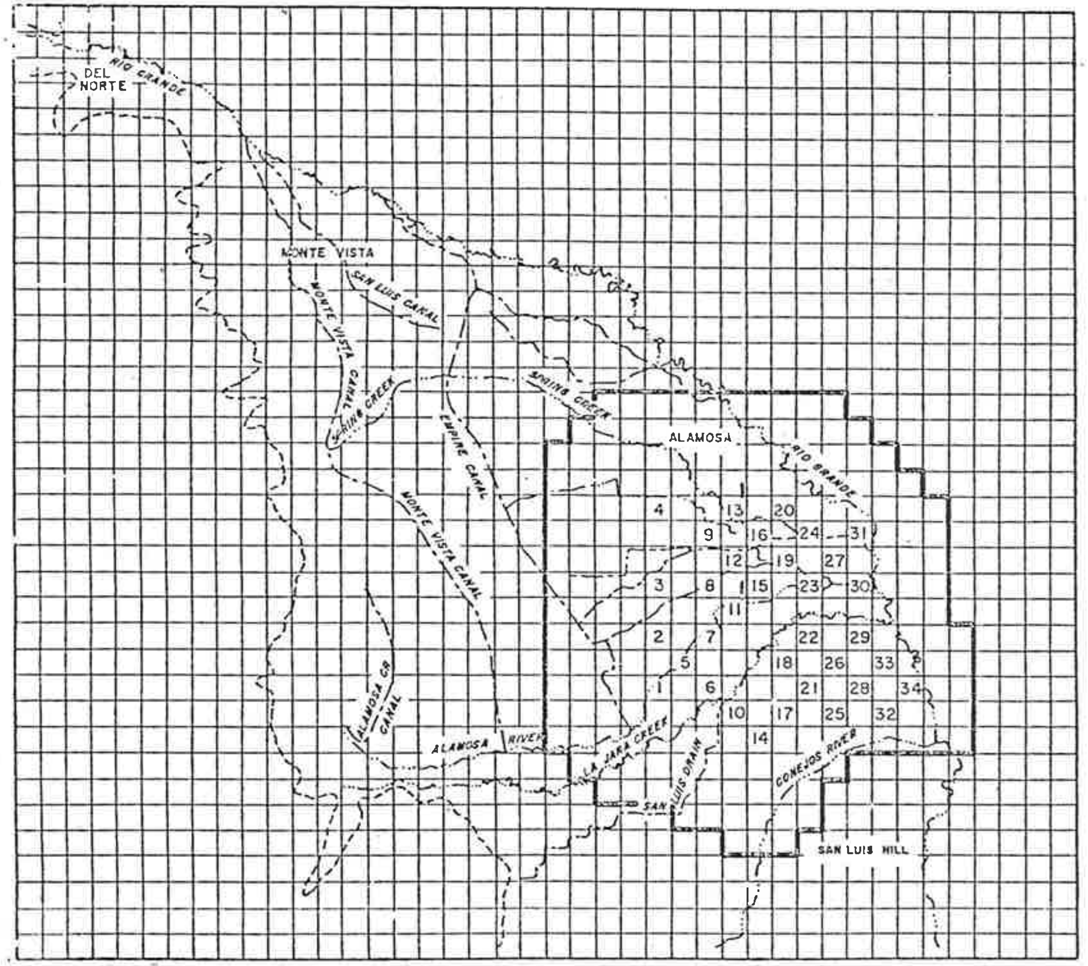

Figure 3. Observation Area Grid System and the 34 Calculation Cells

Climatically Controlled Components

The climatically controlled components are also physical components, however, they are governed by the annual cycle and consequently vary from year to year. The climatic conditions prevailing in the San Luis Valley result in the need for irrigated agriculture. The average rainfall is very low, resulting in a deficiency of moisture during the crop growing season. In turn the demand for surface water from diversions of streamflow is very high. A result of the high water table levels in the San Luis Valley is the high evapotranspiration which is a true loss of water from the system.

An important decision related to the use of climatic data in the hydrologic model was whether to use a 12 year historic sequence or average values for all the various climatic variables. A standardized year is established by taking this approach. This approach allows more control of the system because the annual cycle is repeated exactly during each of the 12 simulation years in the hydrologic model. However, the monthly fluctuations in the water budget are still retained. Consequently the changes due to the various management strategies are more easily detectable. The averages of the climatic variables are based on a 30 year period (1935-1964). The standard year also greatly facilitates data handling and storage requirements in the computer model.

CONCLUSIONS

This paper is too succinct to do justice to the complex hydrologic model used for assessing waterlogging controls. The interested reader should consult detailed reports on the subject (Simpson et al., 1980a; Simpson et al., 1980b). The validity and the value of the model can be inferred from the companion paper (Young et al., 1983). In this second paper a (good) comparison of predicted and observed Rio Grande outflows from the system is provided. Comparison of several control strategies shows clearly the pros and cons of the strategies tested.

REFERENCES

Dunford, D. S. 1982. "Optimal Drain Design" Ph.D. thesis, Dept. of Civil Engineering, Colorado State University, Fort Collins, Colorado.

Fitz, J. C., G. L. Horner and J. H. Snyder. 1980. "The Economic Feasibility of Installing Subsurface Tile Drainage in the Panoche Water District, San Joaquin Valley, California." Bulletin 1897, Division of Agricultural Sciences, University of California at Davis, Davis, California, March 1980.

Food and Agricultural Organization of the United Nations. 1973. "Irrigation, Drainage and Salinity: An International Source Book" Paris, Hutchinson.

Johnson, S. H. 1975. "The Economics of Water Management to Reduce Waterlogging and Salinity: San Luis Valley, Colorado." Ph.D. Dissertation, Department of Economics, Colorado State University, Fort Collins, Colorado, 1975.

Luthin, J. N., ed. "Drainage of Agricultural Lands", Agronomy Monograph No. 7, Madison, Wisconsin, 1957.

Morel-Seytoux, H. J. 1979. "Cost-Effective Methodology for Stream-Aquifer Interaction Modeling and Use in Management of Large Scale Systems" HYDROWAR Program Report, Colorado State University, Fort Collins, Colorado, December 1979, 75 pages.

Simpson, A. A., H. J. Morel-Seytoux, F. G. Baker, G. C. Mishra, John Daubert, Roy Koch, R. A. Young and W. T. Franklin. 1980a. "Hydrologic Study of San Luis Valley, Colorado, using a Stream-Aquifer Interaction Model." HYDROWAR Program Report, Colorado State University, Fort Collins, Colorado, September 1980, 252 pages.

Simpson, A. A., H. J. Morel-Seytoux, R. A. Young, G. E. Radosevich and W. T. Franklin. 1980b. "Waterlogging Control for Improved Water and Land Use Efficiencies: a Systematic Analysis." Completion Report No. 108, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, December 1980, 138 pages.

Van Schilfgaarde, Jan, ed. 1974. "Drainage for Agriculture" Agronomy Monograph No. 17, American Society of Agronomy, Madison, Wisconsin.

White House and U.S. Dept. of the Interior. 1964. "Water and Land Development in the Indus Plain" Report by Panel on Waterlogging and Salinity in West Pakistan, U.S. Government Printing Office, Washington, D.C.

Young, R. A., H. J. Morel-Seytoux and A. R. Simpson. 1983. Assessing Waterlogging Controls II: Impact Forecasts. These Proceedings.